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Research on the Response of Submerged Rloating Tunnel under Fatigue Loads

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Abstract

Submerged floating tunnel(SFT) has coused worldwide concern as an innovative large span structure. A refined 3D finite element structural model is established for a submerged floating tunnel， the response under fatigue loads is investigated and the weak points of strucure analysed, while the loads include traffic load, fluid forces, wave impactions. The results shows that: 1) Near the connection section of anchor cable, fatigue damage would be easily generated due to the .2)If the space between anchor cable is dense enough, the stress and displacement at tubulation midspan would not change a lot. 3)If there appears rather strong stress area in the upper part of anchoring tubulation,instability should be noticed.

Keywords:Fatigue load, Submerged floating tunnel, Finite element structural model, Response, Fatigue damage

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1. Background

Submerged floating tubes allow construction of a tunnel in extremely deep water, where conventional bridges or tunnels are technically difficult or prohibitively expensive. They would be able to deal with seismic disturbances and weather events easily, and their structural performance is independent of length that is, it can be very long without compromising its stability and resistance, thus it has coused worldwide concern as an innovative large span structure in recent yeas.

Nomenclature

F(t)	the total inline force on the object	F_I	the inertia force
Cm = 1 + Cs	the inertia coefficient		
Cs	the added mass coefficient	A	a reference area
V	volume of the body		

The study of the submerged floating tunnel in the Strait of Messina has been promoted by Ponte di Archimede S.p.A. and verified with a feasibility analysis by the Italian Naval Register (RINA). The SIJLAB (Sino-Italian Joint Laboratory of Archimedes' Bridge), the Chinese Ministry of Science and Technology and the Institute of Mechanics of the Chinese Academy of Sciences have started to build a 100m demonstration tunnel in Qiandao Lake in China eastern province of Zhejiang. Inside it, two layers of one-way motorways will run though in the middle, with two railway tracks flanking them. The Qiandao Lake prototype will serve to help plan for the project of a 3,300-meter submerged floating tunnel in the Jintang Strait, in the Zhoushan archipelago, also situated in Zhejiang. Indonesia has also expressed interest in this technology. Undersea tunnel could be an alternative to connect adjacent islands, in addition to bridges.

However, there are lots of constraints to build such tunnels in deeper water both on cost and technique aspects . As a result of directly exposed in the natural enviromnent with wave and flow the unusual loads produced by these actions constitute one of the major surrounding forces loaded on the SFT. The wave action, traffic loads, which vary as a funtion of time , will cause dynamic response，and couse fatigue damage to the structure members, especially at some local areas where are vulnerable to fatigue. Therefore the response and the weak points of strucure under fatigue loads should be analysed carefully for the structural security and durability.

2. Common types and characteristics of SFT

SFT is an innovative concept for crossing waterways, utilizing the law of buoyancy to support the structure at a moderate and convenient depth. The main components are:tube, anchoring and shore connections.The tube like structure is flexible and designed to accommodate road or rail traffic, as shown in Fig.1. The ballast used is calculated so that the structure has approximate hydrostatic equilibrium (that is, the tunnel is roughly the same overall density as water), whereas immersed tube tunnels are ballasted more to weight them down to the sea bed.Fig.2 indicates a typical section of SFT, and Fig.3 illustrates an new structure type combined suspension bridge with SFT.

Figure 1. Submerged floating tunnel

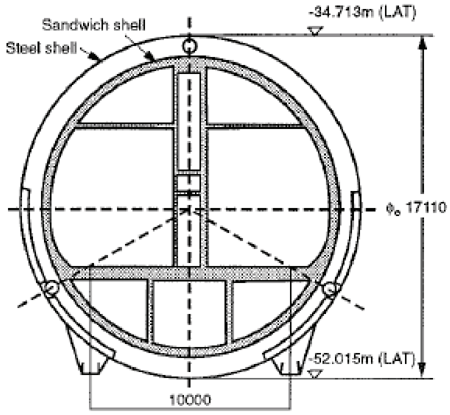


Figure 2. Typical section

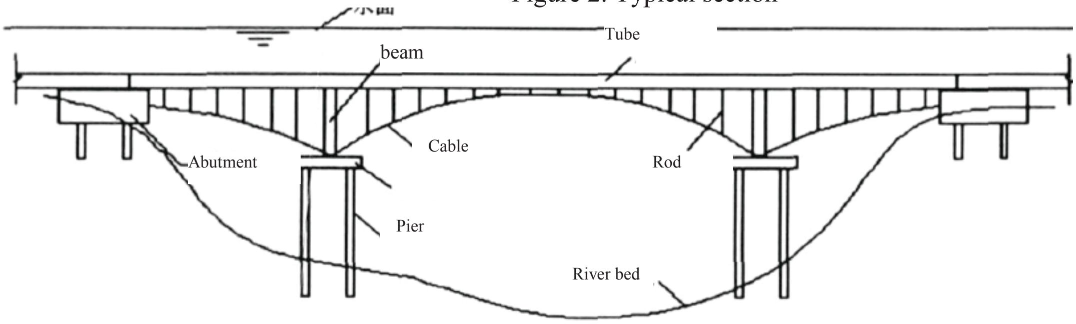


Figure 3. Reverse suspended cable SFT

The major benefit of SFT technology is related to the very low environmental impact to both landscape and pollution. Additonal benefits are its lower energy consumption and the absence of any interference with water surface traffic.

3. Fatigue Loads and their simulations

Loads include permanent loads and functional loads, such as dead weight, traffic etc. just the same as other bridges, but the environmental loads on SFT are complicated, which include:current, wave(wind waves, internal waves, ship induced waves,rockslide induced waves, tidal waves and so on), variations of water level, earthquake, thermal variations, ice, corrosion, marine growth, and accidental actions, which include: collisions,fishing nets,flooding,leakage are also concerned. Each of these loads has to be identified, and used in suitable models, sometimes probabilistic models or combination models required.

3.1. Wave loads

In fluid dynamics the Morison equation is a semi-empirical equation for the inline force on a body in oscillatory flow and used to estimate the wave loads in the design of offshore structures. In an oscillatory flow with flow velocity u(t), the Morison equation gives the inline force parallel to the flow direction (as shown in Eq.1):

$$F = \underbrace{\rho C_m V \dot{u}}_{F_I} + \underbrace{\frac{1}{2}\rho C_d A u |u|}_{F_D}. \tag{1}$$

The Morison equation is a heuristic formulation of the force fluctuations in an oscillatory flow. The first assumption is that the flow acceleration is more-or-less uniform at the location of the body. Second, it is assumed that the asymptotic forms: the inertia and drag force contributions, valid for very small and very large Keulegan–Carpenter numbers respectively, can just be added to describe the force fluctuations at intermediate Keulegan–Carpenter numbers.

However, from experiments it is found that in this intermediate regime - where both drag and inertia are giving significant contributions — the Morison equation is not capable to describe the force history very well. Although the inertia and drag coefficients can be tuned to give the correct extreme values of the force. Third, when extended to orbital flow which is a case of non uni-directional flow, for instance encountered by a horizontal cylinder under waves, the Morison equation does not give a good representation of the forces as a function of time.

3.2. Traffic loads

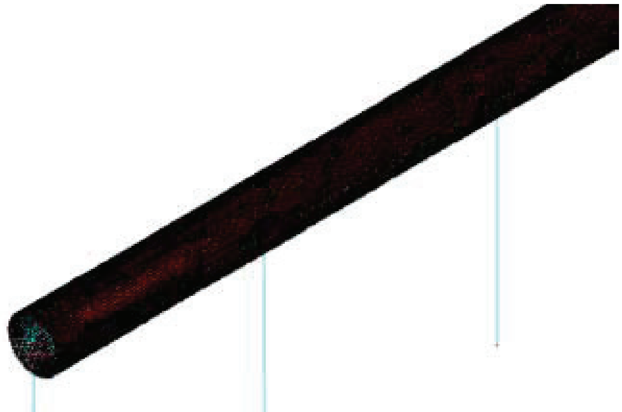
Load spectra are often used instead of real load history and conservative result is obtained. The regularity of the load case (full load or empty load), and transport quantity of every year and load case (the number of cars, the ratio of empty load) can be obtained. So the load spectra based on that can represent the real load history of bridge. On the basis of load character the method of getting load spectra (include method of traffic investigation and building of model car) is elicited. And MonteCalor method of is used to simulate the traffic flow, Where the distances between vehicles keeps to Weibull Distribution(as shown in Eq.2), the weights of vehicles keeps to normal distribution.

$$f(x)=\begin{cases} 0, & x \le b_1 \\ c\cdot\left[p\cdot\dfrac{1}{\sqrt{2\pi}\sigma_1}e^{-\frac{1}{2}\left(\frac{x-\mu_1}{\sigma_1}\right)^2}+(1-p)\cdot\dfrac{1}{\sqrt{2\pi}\sigma_2}e^{-\frac{1}{2}\left(\frac{x-\mu_2}{\sigma_2}\right)^2}\right], & b_1 < x \le b_2 \\ 0, & x > b_2 \end{cases} \tag{2}$$

4. Structural analysis model

A refined 3D model is established for a SFT using a FEM structural analysis software, which include tube, anchors. The main work steps are shown as follows：

- Model the members of the tube with 3D-Shell elements, anchor rod with 3D-BEAM elements, and the anchor rods were connected with the tube by share nodes.
- Mesh the partial near crack as singular elements, as shown in Fig.4.



- Fluid modeled as 3D FLUID elements, and the fluid actions simulated by Fluid-solid coupling.
- Apply loads and constraints, where loads include traffic and wave loads, and all connections are rigid.

5. Results

Solve the model under given loads, the stress and diformation of whole struture were acquired as shown as Fig.5 and Fig.6 respectively.

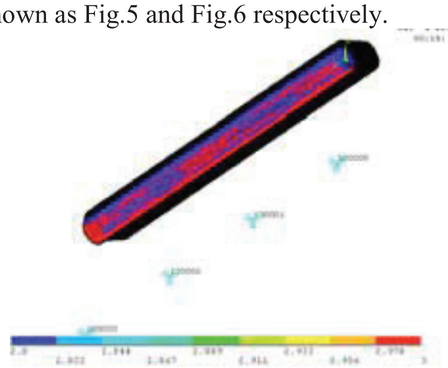


Figure.5 Displacements at y-axis (mm)

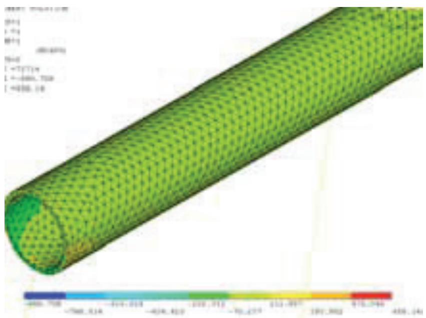


Figure.6 Stress of tube

6. Conclusions

The results shows that: 1) Near the connection section of anchor cable, fatigue damage would be easily generated due to the concentrated force.2)If the space between anchor cable is dense enough, the stress and displacement at tubulation midspan would not change a lot, so the whole span could not limited by regular loads, such as dead loads and traffic loads. 3)There appears rather strong stress area in the upper part of ancshoring tubulation, instability should be noticed.

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